

# Fragmentation fractions of two-body $b$ -baryon decays

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(Dated: October 8, 2015)

## Abstract

We study the fragmentation fractions ( $f_{\mathbf{B}_b}$ ) of the  $b$ -quark to  $b$ -baryons ( $\mathbf{B}_b$ ). By the assumption of  $f_{\Lambda_b}/(f_u + f_d) = 0.25 \pm 0.15$  in accordance with the measurements by LEP, CDF and LHCb Collaborations, we estimate that  $f_{\Lambda_b} = 0.175 \pm 0.106$  and  $f_{\Xi_b^-,0} = 0.019 \pm 0.013$ . From these fragmentation fractions, we derive  $\mathcal{B}(\Lambda_b \rightarrow J/\psi\Lambda) = (3.3 \pm 2.1) \times 10^{-4}$ ,  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi\Xi^-) = (5.3 \pm 3.9) \times 10^{-4}$  and  $\mathcal{B}(\Omega_b^- \rightarrow J/\psi\Omega^-) > 1.9 \times 10^{-5}$ . The predictions of  $\mathcal{B}(\Lambda_b \rightarrow J/\psi\Lambda)$  and  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi\Xi^-)$  clearly enable us to test the theoretical models, such as the QCD factorization approach in the  $b$ -baryon decays.

## I. INTRODUCTION

The LHCb Collaboration has recently published the measurements of the  $b$ -baryon ( $\mathbf{B}_b$ ) decays [1–3], such as the charmful  $\Lambda_b$  decays of  $\Lambda_b \rightarrow \Lambda_c^+(K^-, \pi^-)$ ,  $\Lambda_b \rightarrow \Lambda_c^+(D^-, D_s^-)$ ,  $\Lambda_b \rightarrow D^0 p(K^-, \pi^-)$ , and  $\Lambda_b \rightarrow J/\psi p(K^-, \pi^-)$ , which are important and interesting results. For example, while the  $p\pi$  mass distribution in  $\Lambda_b \rightarrow J/\psi p\pi^-$  [2] suggests the existence of the higher-wave baryon, such as  $N(1520)$  or  $N(1535)$ , a peaking data point in the  $Dp$  mass distribution in  $\Lambda_b \rightarrow D^0 p(K^-, \pi^-)$  [3] hints at the resonant  $\Sigma_c(2880)$  state. On the other hand, it is typical to have the partial observations for the decay branching ratios, given by [4]

$$\begin{aligned}\mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) f_{\Lambda_b} &= (5.8 \pm 0.8) \times 10^{-5}, \\ \mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi_b^-) f_{\Xi_b^-} &= (1.02_{-0.21}^{+0.26}) \times 10^{-5}, \\ \mathcal{B}(\Omega_b^- \rightarrow J/\psi \Omega_b^-) f_{\Omega_b^-} &= (2.9_{-0.8}^{+1.1}) \times 10^{-6},\end{aligned}\tag{1}$$

where  $f_{\mathbf{B}_b}$  are the fragmentation fractions of the  $b$  quark to  $b$ -baryons  $\mathbf{B}_b = \Lambda_b, \Xi_b^-$  and  $\Omega_b^-$ . The partial observations in Eq. (1) along with the measurements of the  $\Xi_b^0$  decays [3–5] are due to the fact that  $f_{\Lambda_b, \Xi_b^-, \Omega_b^-}$  are not well determined. In the assumption of  $f_{\Lambda_b} \simeq f_{baryon}$  with  $f_{baryon} \equiv \mathbf{B}(b \rightarrow \text{all } b\text{-baryons})$ , it is often adopted that  $f_{\Lambda_b} = 0.1$  [6, 7]<sup>1</sup>. However, according to the recent observations of the relatively less decays associated with  $\Xi_b^{-,0}$  and  $\Omega_b^-$  [8],  $f_{\Lambda_b} \simeq f_{baryon}$  is no longer true. As a result, it is urgent to improve the value of  $f_{\Lambda_b}$  and obtain the less known ones of  $f_{\Xi_b^{-,0}}$ .

Although it is possible to estimate  $f_{\Lambda_b}$  by the ratio of  $f_{\Lambda_b}/(f_u + f_d)$  with  $f_{u,d,s} \equiv \mathcal{B}(b \rightarrow B^-, \bar{B}^0, \bar{B}_s^0)$ , different measurements on  $f_{\Lambda_b}/(f_u + f_d)$  are not in good agreement, given by

$$\begin{aligned}f_{\Lambda_b}/(f_u + f_d) &= 0.281 \pm 0.012(\text{stat})_{-0.056}^{+0.058}(\text{sys})_{-0.087}^{+0.128}(\text{Br}) \quad [9], \\ f_{\Lambda_b}/(f_u + f_d) &= 0.125 \pm 0.020 \quad [4],\end{aligned}\tag{2}$$

with the uncertainty related to Br due to the uncertainties on the measured branching ratios, where the first relation given by the CDF Collaboration [9] is obviously two times larger than the world averaged value of the second one [4], dominated by the LEP measurements on  $Z$  decays. Moreover, since the recent measurements by the LHCb Collaboration also indicate this inconsistency [10–12], it is clear that the values of  $f_{\Lambda_b}$  and  $f_{\Xi_b^{-,0}}$  can not be experimentally

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<sup>1</sup>  $f_{baryon} \sim 0.1$  was also taken in the previous versions of the PDG.

determined yet. In this paper, we will demonstrate the possible range for  $f_{\Lambda_b}/(f_u + f_d)$  in accordance with the measurements by LEP, CDF and LHCb Collaborations and give the theoretical estimations of  $f_{\Lambda_b}$  and  $f_{\Xi_b^{0,-}}$ , which allow us to extract  $\mathcal{B}(\Lambda_b \rightarrow J/\psi\Lambda)$ ,  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi\Xi^-)$ , and  $\mathcal{B}(\Omega_b^- \rightarrow J/\psi\Omega^-)$  from the data in Eq. (1). Consequently, we are able to test the theoretical approach based on the factorization ansatz, which have been used to calculate the two-body  $\mathbf{B}_b$  decays [7, 13–19].

## II. ESTIMATIONS OF $f_{\Lambda_b}$ AND $f_{\Xi_b^{0,-}}$

Experimentally, in terms of the specific cases of the charmful  $\Lambda_b \rightarrow \Lambda_c^+\pi^-$  and  $\bar{B}^0 \rightarrow D^+\pi^-$  decays or the semileptonic  $\Lambda_b \rightarrow \Lambda_c^+\mu^-\bar{\nu}X$  and  $\bar{B} \rightarrow D\mu^-\bar{\nu}X$  decays detected with the bins of  $p_T$  and  $\eta$ , where  $p_T$  is the transverse momentum and  $\eta = -\ln(\tan\theta/2)$  is the pseudorapidity defined by the polar angle  $\theta$  with respect to the beam direction [9–11], the ratio of  $f_{\Lambda_b}/(f_u + f_d)$  can be related to  $p_T$  and  $\eta$ . This explains the inconsistency between the results from CDF and LEP with  $p_T = 15$  and 45 GeV, respectively. While  $f_s/f_u$  is measured with slightly dependences on  $p_T$  and  $\eta$  [20],  $f_{\Lambda_b}/(f_u + f_d)$  is fitted as the linear form in Ref. [10] with  $p_T = 0 - 14$  GeV and the exponential form in Refs. [11, 12] with  $p_T = 0 - 50$  GeV, respectively, for the certain range of  $\eta$ .

### A. The present status of $f_{\Lambda_b}/(f_u + f_d)$

With the semileptonic  $\Lambda_b \rightarrow \Lambda_c^+\mu^-\bar{\nu}X$  and  $\bar{B} \rightarrow D\mu^-\bar{\nu}X$  decays, the LHCb Collaboration has shown the dependence of  $f_{\Lambda_b}/(f_u + f_d)$  on  $p_T$  in the range of  $p_T = 0 - 14$  GeV to be the linear form, given by [11]

$$f_{\Lambda_b}/(f_u + f_d) = (0.404 \pm 0.017(\text{stat}) \pm 0.027(\text{syst}) \pm 0.105(\text{Br})) \\ (1 - [0.031 \pm 0.004(\text{stat}) \pm 0.003(\text{syst})]p_T), \quad (3)$$

where Br arises from the absolute scale uncertainty due to the poorly known branching ratio of  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ . By averaging  $f_{\Lambda_b}/(f_u + f_d)$  with  $p_T = 0 - 14$  GeV, we obtain

$$\bar{f}_{\Lambda_b} = (0.316 \pm 0.087)(f_u + f_d), \quad (4)$$

which agrees with the first relation in Eq. (2) given by the CDF Collaboration with  $p_T \simeq 15$  GeV. On the other hand, with the charmful  $\Lambda_b \rightarrow \Lambda_c^+\pi^-$  and  $\bar{B}^0 \rightarrow D^+\pi^-$  decays, another

analysis by the LHCb Collaboration presents the exponential dependence of  $f_{\Lambda_b}/f_d$  on  $p_T$  [11, 12]:

$$f_{\Lambda_b}/f_d = (0.151 \pm 0.030) + \exp\{-(0.57 \pm 0.11) - (0.095 \pm 0.016)p_T\}, \quad (5)$$

with the wider range of  $p_T = 0 - 50$  GeV. By averaging the value in Eq. (5) with  $p_T = 0 - 50$  GeV, we find

$$\bar{f}_{\Lambda_b} = (0.269 \pm 0.040)f_d = (0.135 \pm 0.020)(f_u + f_d), \quad (6)$$

with  $f_u = f_d$  due to the isospin symmetry, where the error has combined the uncertainties in Eq. (5). It is interesting to note that, as the relation in Eq. (5) with  $p_T = 0 - 50$  GeV overlaps  $p_T \simeq 45$  GeV for the second relation from LEP in Eq. (2), its value of  $\bar{f}_{\Lambda_b} = (0.135 \pm 0.020)(f_u + f_d)$  is close to the LEP result of  $f_{\Lambda_b} = (0.125 \pm 0.020)(f_u + f_d)$ . Apart from the values in Eqs. (4) and (6), the reanalyzed results by CDF and LHCb Collaborations give  $f_{\Lambda_b}/(f_u + f_d)$  to be  $0.212 \pm 0.058$  and  $0.223 \pm 0.022$  with the averaged  $p_T \simeq 13$  and 7 GeV, respectively [12]. We hence make the assumption of

$$R_{\Lambda_b} \equiv f_{\Lambda_b}/(f_u + f_d) = 0.25 \pm 0.15, \quad (7)$$

to cover the possible range in accordance with the measurements from the three Collaborations of LEP, CDF and LHCb, which will be used to estimate the values of  $f_{\Lambda_b}$  and  $f_{\Xi_b^{0,-}}$  in the following.

## B. Theoretical determination of $f_{\Xi_b^-}/f_{\Lambda_b}$

In principle, when the ratios of  $f_{\Lambda_b}/(f_u + f_d)$  and  $f_{\Xi_b^{0,-}}/f_{\Lambda_b}$  are both known, by adding the relations of [4, 20]

$$\begin{aligned} f_u + f_d + f_s + f_{baryon} &= 1, \\ f_{baryon} &\simeq f_{\Lambda_b} + f_{\Xi_b^-} + f_{\Xi_b^0}, \\ f_s &= (0.256 \pm 0.020)f_d, \end{aligned} \quad (8)$$

and  $f_u = f_d$  as well as  $f_{\Xi_b^-} = f_{\Xi_b^0}$  due to the isospin symmetry, we can derive the values of  $f_u$ ,  $f_d$ ,  $f_s$ ,  $f_{\Lambda_b}$ ,  $f_{\Xi_b^-}$  and  $f_{\Xi_b^0}$ . For  $f_{\Xi_b^-}/f_{\Lambda_b}$ , it was once given that

$$\begin{aligned} f_{\Xi_b^-}/f_{\Lambda_b} &\simeq f_s/f_u \text{ [8, 21]}, \\ f_{\Xi_b^0}/f_{\Lambda_b} &\simeq 0.2 \text{ [22]}, \end{aligned} \quad (9)$$

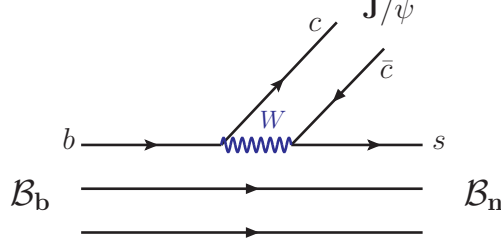


FIG. 1. The  $\mathbf{B}_b \rightarrow \mathbf{B}_n J/\psi$  decays via the internal  $W$ -boson emission diagram.

where the first relation from Refs. [8, 21] requires the assumption of  $R_1 \equiv \mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi^-)/\mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) \simeq 1$  [11], while the second one from Ref. [22] uses  $R_2 \equiv \mathcal{B}(\Xi_b^0 \rightarrow \Xi_c^+ \pi^-)/\mathcal{B}(\Lambda_b \rightarrow \Lambda_c^+ \pi^-) \simeq 1$  along with  $R_3 \equiv \mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)/\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+) \simeq 0.1$  from the naive Cabibbo factors. However, we note that the theoretical calculations provide us with more understanding of  $b$ -baryon decays, such as the difference between the  $\Lambda_b \rightarrow \Lambda$  and  $\Xi_b^- \rightarrow \Xi^-$  transitions, based on the  $SU(3)$  flavor and  $SU(2)$  spin symmetries. As a result, the assumption of  $R_1 = R_2 \simeq 1$  might be too naive. Since the theoretical approach with the factorization ansatz well explains  $\mathcal{B}(\Lambda_b \rightarrow p \pi^-)$  and  $\mathcal{B}(\Lambda_b \rightarrow p K^-)$ , and particularly the ratio of  $\mathcal{B}(\Lambda_b \rightarrow p \pi^-)/\mathcal{B}(\Lambda_b \rightarrow p K^-) \sim 0.84$  [23], it can be reliable to determine  $f_{\Xi_b^-}/f_{\Lambda_b}$ .

Theoretically, we use the factorization approach to calculate the two-body  $b$ -baryon decay, such that the amplitude corresponds to the decaying process of the  $\mathbf{B}_b \rightarrow \mathbf{B}_n$  transition with the recoiled meson. Explicitly, as shown in Fig. 1, where the  $W$ -boson emission is internal, the amplitude via the quark-level  $b \rightarrow c\bar{c}s$  transition can be factorized as

$$\mathcal{A}(\mathbf{B}_b \rightarrow \mathbf{B}_n J/\psi) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cs}^* a_2 \langle J/\psi | \bar{c} \gamma^\mu (1 - \gamma_5) c | 0 \rangle \langle \mathbf{B}_n | \bar{s} \gamma_\mu (1 - \gamma_5) b | \mathbf{B}_b \rangle, \quad (10)$$

for  $\Lambda_b \rightarrow \Lambda J/\psi$  or  $\Xi_b^- \rightarrow \Xi^- J/\psi$ , where the parameter  $a_2$  is given by [24, 25]

$$a_2 = c_2^{eff} + \frac{c_1^{eff}}{N_c}, \quad (11)$$

with the effective Wilson coefficients  $(c_1^{eff}, c_2^{eff}) = (1.168, -0.365)$ . Note that the color number  $N_c$  originally being equal to 3 in the naive factorization, which gives  $a_2 = 0.024$  in Eq. (11), should be taken as a floating number from  $2 \rightarrow \infty$  to account for the non-factorizable effects in the generalized factorization. The matrix element for the  $J/\psi$  production is given by  $\langle J/\psi | \bar{c} \gamma_\mu c | 0 \rangle = m_{J/\psi} f_{J/\psi} \varepsilon_\mu^*$  with  $m_{J/\psi}$ ,  $f_{J/\psi}$ , and  $\varepsilon_\mu^*$  as the mass, decay

constant, and polarization vector, respectively. The matrix elements of the  $\mathbf{B}_b \rightarrow \mathbf{B}_n$  baryon transition in Eq. (10) have the general forms:

$$\begin{aligned}\langle \mathbf{B}_n | \bar{q} \gamma_\mu b | \mathbf{B}_b \rangle &= \bar{u}_{\mathbf{B}_n} [f_1 \gamma_\mu + \frac{f_2}{m_{\mathbf{B}_b}} i \sigma_{\mu\nu} q^\nu + \frac{f_3}{m_{\mathbf{B}_b}} q_\mu] u_{\mathbf{B}_b}, \\ \langle \mathbf{B}_n | \bar{q} \gamma_\mu \gamma_5 b | \mathbf{B}_b \rangle &= \bar{u}_{\mathbf{B}_n} [g_1 \gamma_\mu + \frac{g_2}{m_{\mathbf{B}_b}} i \sigma_{\mu\nu} q^\nu + \frac{g_3}{m_{\mathbf{B}_b}} q_\mu] \gamma_5 u_{\mathbf{B}_b},\end{aligned}\quad (12)$$

where  $f_j$  ( $g_j$ ) ( $j = 1, 2, 3$ ) are the form factors, with  $f_{2,3} = 0$  and  $g_{2,3} = 0$  due to the helicity conservation, as derived in Refs. [7, 14, 26]. It is interesting to note that, as the helicity-flip terms, the theoretical calculations from the loop contributions to  $f_{2,3}$  ( $g_{2,3}$ ) indeed result in the values to be one order of magnitude smaller than that to  $f_1$  ( $g_1$ ), which can be safely neglected. In the double-pole momentum dependences, one has that [23]

$$F(q^2) = \frac{F(0)}{(1 - q^2/m_{\mathbf{B}_b}^2)^2}, \quad (F = f_1, g_1). \quad (13)$$

We are able to relate different  $\mathbf{B}_b \rightarrow \mathbf{B}_n$  transition form factors based on  $SU(3)$  flavor and  $SU(2)$  spin symmetries, which have been used to connect the space-like  $\mathbf{B}_n \rightarrow \mathbf{B}'_n$  transition form factors in the neutron decays [27], and the time-like  $0 \rightarrow \mathbf{B}_n \bar{\mathbf{B}}'_n$  baryonic as well as  $B \rightarrow \mathbf{B}_n \bar{\mathbf{B}}'_n$  transition form factors in the baryonic  $B$  decays [28–32]. As a result, we obtain  $(f_1(0), g_1(0)) = (C, C)$ ,  $(-\sqrt{2/3}C, -\sqrt{2/3}C)$ , and  $(0, 0)$  with  $C$  a constant for  $\langle p | \bar{u} \gamma_\mu (\gamma_5) b | \Lambda_b \rangle$ ,  $\langle \Lambda | \bar{s} \gamma_\mu (\gamma_5) b | \Lambda_b \rangle$ , and  $\langle \Sigma^0 | \bar{s} \gamma_\mu (\gamma_5) b | \Lambda_b \rangle$ , which are the same as those in Ref. [26] based on the heavy-quark and large-energy symmetries for the  $\Lambda_b \rightarrow (p, \Lambda, \Sigma^0)$  transitions, respectively. In addition, we have  $f_1(0) = g_1(0) = C$  for  $\langle \Xi^- | \bar{s} \gamma_\mu (\gamma_5) b | \Xi_b^- \rangle$ . To obtain the branching ratio for the two-body decays, the equation is given by [4]

$$\mathcal{B}(\mathbf{B}_b \rightarrow J/\psi \mathbf{B}_n) = \frac{\Gamma(\mathbf{B}_b \rightarrow J/\psi \mathbf{B}_n) \tau_{\mathbf{B}_b}}{6.582 \times 10^{-25}}, \quad (14)$$

with  $\tau_{\mathbf{B}_b}$  the life time, where

$$\Gamma(\mathbf{B}_b \rightarrow J/\psi \mathbf{B}_n) = \frac{|\vec{P}_{J/\psi}|}{8\pi m_{\mathbf{B}_b}^2} |\mathcal{A}(\mathbf{B}_b \rightarrow J/\psi \mathbf{B}_n)|^2, \quad (15)$$

with  $|\vec{P}_{J/\psi}| = |\vec{P}_{\mathbf{B}_n}| = \{[m_{\mathbf{B}_b}^2 - (m_{J/\psi} + m_{\mathbf{B}_n})^2][m_{\mathbf{B}_b}^2 - (m_{J/\psi} - m_{\mathbf{B}_n})^2]\}^{1/2}/(2m_{\mathbf{B}_b})$ . As a result, we obtain

$$\frac{\mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi^-)}{\mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)} = \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b}} \frac{C^2}{(-\sqrt{2/3}C)^2} = 1.63 \pm 0.04, \quad (16)$$

with  $\tau_{\Xi_b^-}/\tau_{\Lambda_b} = 1.089 \pm 0.026 \pm 0.011$  [33]. We note that, theoretically,  $R_1 = 1.63$  apparently deviates by 63% from  $R_1 = 1$  in the simple assumption. To determine  $f_{\Xi_b^-}/f_{\Lambda_b}$ , we relate Eq. (16) to (1) to give

$$f_{\Xi_b^-} = (0.108 \pm 0.034)f_{\Lambda_b}, \quad (17)$$

which is different from the numbers in Eq. (9).

### C. Determinations of $f_{\Xi_b^-,0}$ and $f_{\Lambda_b}$

According to Eqs. (4), (7), (8) and (17), we derive the values of  $f_u$ ,  $f_d$ ,  $f_s$ ,  $f_{\Lambda_b}$ ,  $f_{\Xi_b^-}$  and  $f_{\Xi_b^0}$  in Table I, which agree with the data in the PDG [4]. Note that  $f_{\Omega_b^-} < 0.108$  is from the error in  $f_{baryon}$ . In addition,  $f_{baryon} = 0.213 \pm 0.108$ , which overlaps  $0.089 \pm 0.015$  from Z-decays [4] and  $0.237 \pm 0.067$  from Tevatron [4], is due to the assumption of  $R_{\Lambda_b} = 0.25 \pm 0.15$  in Eq. (7) to cover the possible range from the data. Similarly,  $f_{\Lambda_b} = 0.175 \pm 0.106$  overlaps  $f_{\Lambda_b} = 0.07$  from the LEP measurements [34], while  $f_{\Xi_b^-} = f_{\Xi_b^0} = 0.019 \pm 0.013$  is consistent with  $f_{\Xi_b^-} = 0.011 \pm 0.005$  from the measurement [35]. We hence convert the data in Eq. (1) to be

$$\begin{aligned} \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) &= (3.3 \pm 2.1) \times 10^{-4}, \\ \mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi^-) &= (5.3 \pm 3.9) \times 10^{-4}, \\ \mathcal{B}(\Omega_b^- \rightarrow J/\psi \Omega^-) &> 1.9 \times 10^{-5}, \end{aligned} \quad (18)$$

TABLE I. Results of  $f_i$  ( $i = u, d, s, \text{baryon}, \Lambda_b, \Xi_b^-,0$ , and  $\Omega_b^-$ ), compared with those from Z-decays and Tevatron in PDG [4].

	our result	Z-decays [4]	Tevatron [4]
$f_u = f_d$	$0.349 \pm 0.037$	$0.404 \pm 0.009$	$0.330 \pm 0.030$
$f_s$	$0.089 \pm 0.018$	$0.103 \pm 0.009$	$0.103 \pm 0.012$
$f_{baryon}$	$0.213 \pm 0.108$	$0.089 \pm 0.015$	$0.237 \pm 0.067$
$f_{\Lambda_b}$	$0.175 \pm 0.106$	—	—
$f_{\Xi_b^-} = f_{\Xi_b^0}$	$0.019 \pm 0.013$	—	—
$f_{\Omega_b^-}$	$< 0.108$	—	—

with  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi^-) \simeq 1.6\mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)$  to be in accordance with Eq. (16). With the use of  $f_{\Xi_b^{0,-}}$ , we can also estimate the  $\Xi_b^{0,-}$  decays [4, 5], given by

$$\begin{aligned}\mathcal{B}(\Xi_b^- \rightarrow \Xi^- \ell^- \bar{\nu}_\ell X) &= (2.1 \pm 1.5) \times 10^{-2}, \\ \mathcal{B}(\Xi_b^0 \rightarrow \bar{K}^0 p \pi^-) &= (1.1 \pm 1.5) \times 10^{-5}, \\ \mathcal{B}(\Xi_b^0 \rightarrow \bar{K}^0 p K^-) &= (1.1 \pm 1.1) \times 10^{-5}, \\ \mathcal{B}(\Xi_b^0 \rightarrow D^0 p K^-) &= (9.5 \pm 9.4) \times 10^{-5}, \\ \mathcal{B}(\Xi_b^0 \rightarrow \Lambda_c^+ K^-) &= (4.2 \pm 4.7) \times 10^{-5}.\end{aligned}\tag{19}$$

#### D. Test of the non-factorizable effects

To numerically test the non-factorizable effects, the CKM matrix elements in the Wolfenstein parameterization are taken as  $(V_{cb}, V_{cs}) = (A\lambda^2, 1 - \lambda^2/2)$  with  $(\lambda, A) = (0.225, 0.814)$  [4], while  $f_{J/\psi} = 418 \pm 9$  MeV [36]. The constant value of  $C$  in Ref. [23] is fitted to be  $C = 0.136 \pm 0.009$  to explain the branching ratios and predict the CP violating asymmetries of  $\Lambda_b \rightarrow p(K^-, \pi^-)$ , which is also consistent with the value of  $0.14 \pm 0.03$  in the light-cone sum rules [26] and those in Refs. [7, 14].

To explain the branching ratios of  $\Lambda_b \rightarrow J/\psi \Lambda$  and  $\Xi_b^- \rightarrow J/\psi \Xi^-$  in Eq. (18), the floating color number  $N_c$  is evaluated to be

$$N_c = 2.15 \pm 0.17,\tag{20}$$

which corresponds to  $a_2 = 0.18 \pm 0.04$ , in comparison with  $a_2 = 0.024$  for  $N_c = 3$ . Note that since  $N_c = 2.15$  in Eq. (20) is not far from 3, we conclude that the non-factorizable effects are controllable. As a result, the theoretical approach based on the factorization ansatz is demonstrated to be reliable to explain the two-body  $\mathbf{B}_b$  decays.

### III. CONCLUSIONS

In sum, we made the assumption of  $R_{\Lambda_b} = f_{\Lambda_b}/(f_u + f_d) = 0.25 \pm 0.15$ , which is in accordance with the measurements by LEP, CDF and LHCb Collaborations. We have estimated that  $f_{\Lambda_b} = 0.175 \pm 0.106$  and  $f_{\Xi_b^{0,-}} = 0.019 \pm 0.013$ , which can be used to extract the branching ratios of the anti-triplet  $b$ -baryon decays. Explicitly, we have found  $\mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) = (3.3 \pm 2.1) \times 10^{-4}$ ,  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi \Xi^-) = (5.3 \pm 3.9) \times 10^{-4}$  and  $\mathcal{B}(\Omega_b^- \rightarrow J/\psi \Omega^-) >$



$1.9 \times 10^{-5}$ . We have also demonstrated that the predictions of  $\mathcal{B}(\Lambda_b \rightarrow J/\psi\Lambda)$  and  $\mathcal{B}(\Xi_b^- \rightarrow J/\psi\Xi^-)$  would help us to test the theoretical models, such as the factorization approach.

## ACKNOWLEDGMENTS

This work was partially supported by National Center for Theoretical Sciences, National Science Council (NSC-101-2112-M-007-006-MY3) and (NSC 101-2112-M-009-004-MY3), MoST (MoST-104-2112-M-007-003-MY3) and National Tsing Hua University (104N2724E1).

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